CASR

FAA Center for Aviation Systems Reliability

Program Summary

August 2002

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Task Title: Optimized Ultrasonic Techniques for Detection and Sizing of Defects in Multilayered Structures

Investigation Team: I. N. Komsky and J. D. Achenbach

Program initiation date: Program initiated as IA005 June 1, 1998 with scheduled ending date of December, 2002.

Objective:

- To support the application and transfer of dual probe ultrasonic techniques in the detection, characterization, and sizing of defects in multilayered aircraft structures.

Research Activities:

- Develop methodology to determine optimal number, types, and spatial orientations of transducer array elements based on spatial orientations/size of aircraft structural elements and defects
- Develop multi-element transducer-positioning head
- Integrate transducer positioning head and coupling unit with transducer module.
- Demonstrate unit at AANC and validate on specific application
- Transfer methodology for development and applications of the transducer arrays to industry

Anticipated Results:

- Prototype system and demonstration data for range of crack detection applications defined by industry partners

Accomplishments:

April 1998**:** Feasibility of the ultrasonic inspection of a T-chord in the Boeing 777 multilayered wing structure has been demonstrated to Boeing NDE personnel.

November, 1998: Calibration specimens manufactured by Boeing have been used to develop ultrasonic technique for sealant assessment and crack detection in the Boeing 777 multilayered wing structure.

November, 1999: Design and manufacturing of the novel interchangeable transducer holder for ultrasonic scanning of areas with limited access using angle-beam contact transducers was completed. The holder was tested on the representative specimens and cutouts from the Boeing 777.

March, 2000: Manufacturing of the prototype miniature flexible scanner for ultrasonic inspection of aircraft structures with curved and spliced surfaces was completed. Ultrasonic images of the Cessna specimens along with the portable units for data acquisition were demonstrated to Cessna.

July-December, 2000: New inspection procedure for crack characterization in the multi-layered aircraft structure has been tested on the Cessna 650fwd-2 specimens.

January-March, 2001: Two inspection procedures have been developed for KC-10 applications and tested on the representative specimens. The results have been sent to Boeing.

April-September, 2001: New crack sizing ultrasonic technique for crack sizing using portable ultrasonic flaw detectors has been developed.

October 2001-March 2002: New crack sizing technique has been demonstrated to Northwest Airlines NDE staff. The technique and the scanning procedure were successfully tested on the DC-10 and Citation 7 structures that were acquired from NWA and Cessna.

Publications:

"Optimization Of A Scanning Procedure For Ultrasonic Characterization Of Radial Fatigue Cracks", Annual Review of Progress in QNDE, Snowbird, Utah, July 20-24, 1998.

"Ultrasonic Maging Of Fatigue Cracks Around Fasteners In Multilayered Airplane Structures", Proceedings of the 1998 Advances in Aviation Safety Conference & Exhibition, SAE, 1998.

"Ultrasonic Imaging Of Cracks In Aging Aircraft Structures", Paper Summaries of the 1998 ASNT Conference, ASNT, 1998.

"Ultrasonic Imaging Of Fatigue Cracks In Multilayered Airplane Structures With Limited Access", in NDE of Aging Aircraft, Airports, and Aerospace Hardware, Proceedings of SPIE, 1998.

"Ultrasonic Characterization Of Radial Fatigue Cracks In Aging Airplane Structures", in NDE of Aging Aircraft, Airports, and Aerospace Hardware, Proceedings of SPIE, 1999.

"Application Of Ultrasonic Line Scanning To Sizing Of Fatigue Cracks In Airplane Structures", Proceeding of The Second Joint NASA/FAA/DoD Conference on Aging Aircraft, NASA, 1999**.**

"Quantitative Characterization Of Cracks Using Ultrasonic Imaging", Presented at QNDE 2000, published in Review of Progress in QNDE, Volume 20.

"Modular Imaging Systems For Ultrasonic Evaluation Of Aircraft Structures", Proceedings of the International Symposium on Nondestructive Testing Contribution to Infrastructure Safety Systems in the 21st Century, Torres, Brazil, 1999.

"Modular Systems For Ultrasonic Imaging In Manufacturing", Proceeding of National Manufacturing Week Conference 2000, NAM/ASME, 2000.

"Quantitative Characterization of Flaws Using Modular Inspection Systems", Presented at ATA NDT Conference 2000.

"Accuracy Of Fatigue Crack Characterization Using Ultrasonic Scanning", presented at QNDE 2001.

"Ultrasonic Techniques For Sealant Evaluation In Airframe Components", presented at QNDE 2001.

"Portable Ultrasonic Systems For Quantitative Characterization Of Fatigue Cracks In Aging Aircraft"**,** Proceeding of The Fourth Joint NASA/FAA/DoD Conference on Aging Aircraft, NASA, 2001

"Multi-Element Adjustable Transducer Arrays For Ultrasonic Scanning Of Aging Aircraft", in Proceedings of SPIE, 2002.

Task Title: Technical Support and Coordination of Inspection Activities

Investigation Team: L. Brasche, Iowa State University

Students: Elaine Gray

Program initiation date: Program initiated as IA006 June 1, 1998 with scheduled ending date of December 2002.

Objective:

- To work with industrial leaders in the areas that impact aviation safety including inspection, life management, materials design and processing, and lifing/risk analysis to understand the areas where airworthiness assurance research is needed.
- To utilize input from these disciplines to define a research program that is responsive to the safety requirements of the FAA and the economic considerations of the industry.
- To work with academic partners of AACE to match their capabilities with the research needs defined by the industry and the FAA.
- To coordinate the inspection related programs with other activities in propulsion, advanced materials, and structural integrity to ensure full leverage of the results.
- To support the transition of technology from FAA R&D programs through coordination with industry, FAA personnel, and AANC.

Research Activities:

NDE techniques are critical to the production and inservice operation of aviation components, both aircraft and propulsion. NDE is applicable to process sensing as well as detection of damage or defects. Understanding the role of NDE in the overall life management of aviation components and systems is essential to the definition, development, and implementation of a successful R&D program. FAA CASR has a well respected reputation within the government, industry, and academic participants in inspection related activities as evidenced by the strong industrial support of the program. The CASR program participants will continue to work with FAA-TC inspection staff to develop and implement reliable and cost-effective inspection tools for application by the aviation industry. Communication of the results including establishment and maintenance of a website, participant and support of ATA NDT Forum activities, and inspection society/standard organizations are primary functions of this task.

Anticipated Results:

Establishment of a CASR website and monthly newsletter which provides timely and useful information to support aviation safety research

Strengthened NDE network among the OEMs and airlines and military inspection personnel which supports future direction of CASR research

Accomplishments:

April 1998: Organized and recorded the results of industry workshop on NDE research needs.

September 1998, 1999 and 2000: Participation in the ATA NDT Forum including CASR/ETC technology demonstrations

March 2001: Organized FPI workshop in conjunction with the ASNT Spring Conference

August 2001: Established CASR website for distribution/publication of research results.

November 2001: Established monthly newsletter for distribution to industry, FAA and other government representatives.

Publications:

"The Use of NDT in Jet Engine Applications", L. Brasche, Materials Evaluation, July 2002.

"Aerospace Applications of Radiography", Don Hagemair, Huntington Beach, Ca., formerly NDT Technical Fellow – Boeing, and Lisa Brasche, Ames, Iowa, Associate Director of the Center for NDE, Iowa State University, book chapter to be published in ASNT Radiography Handbook, 2002.

"Successful Implementation of FAA Research Address the Disk Inspection Initiative", K. Smith and L. Brasche, in Proceedings of the 5th Annual FAA/NASA/DOD Aging Aircraft Conference, to be published, 2001.

Task Title: A Modular Imaging System for Ultrasonic Inspection of Multilayered Airplane Structures for Cracks and Corrosion

Investigation Team: I. M. Komsky and J. D. Achenbach, Northwestern University

Program initiation date: Program initiated as IA007, June 23, 1998 with scheduled ending date of June 30, 2002.

Objective:

- To develop a modular inspection system for use in a variety of ultrasonic testing procedures.

Research Activities:

- Define inspection requirements/geometries in cooperation with industry partners
- Design prototype scanning units which do not require direct placement of the scanner on the component using interchangeable mounting plates and commercial transducers
- Develop appropriate data acquisition and data display (imaging) schemes. The system will be utilized to detect, characterize, and image fatigue cracks and corrosion in second and third layers of multilayered airplane structures, from outside surfaces without disassembly. For corrosion inspection a complete map of material loss and/or residual thicknesses of the internal layers will be provided. For crack inspection an image of the crack will be displayed with complete information on crack size, location, orientation, and shape. The
- Transition capability through field demo and validation activities in cooperation with AANC and industry. The inspection system will be deployed on surfaces with limited and/or obstructed access, such as surfaces with protruding fasteners, channels, doublers, angles, etc.

Anticipated Results:

- Application of UT imaging to multilayered structures using existing airline maintenance equipment. Inspection approaches will be developed to facilitate the use of scanning capability in typical shop environments for both crack and corrosion detection in multilayered structures. Applications will include complicated structure such as protruding rivets, channels, double, etc.

Accomplishments:

June 1998: Inspection system based on the portable ultrasonic flaw detector has been tested on a DC-10 airplane at NWA, Minneapolis, MN.

December 1998: Modified version of the rotational scanning inspection system has been integrated with the portable ultrasonic flaw detector EPOCH III.

March 1999: Work has begun to modify a scanning module. New design of a coupling module will make it possible to inspect all fasteners (1 through 12) in a DC-10 spar-cap/strap connection regardless of their proximity to sides of the channel. The modified unit can also be deployed to inspect structural elements with various spatial orientations.

November 1999 – December 1999: The wide area ultrasonic inspection system (positioning and coupling modules, vacuum control module, and rotational ultrasonic scanner) was integrated with a

portable ultrasonic flaw detector and tested on the DC-10 representative specimens and the Boeing 777 wing structure.

July-December, 2000: Work has been completed to develop miniature control module for integration with Krautkramer-Branson DMS2. The module was integrated with DMS2 and tested on Boeing, Fairchild, and Cessna wing structures. The scanning and control modules for Panametrics and Krautkramer-Branson portable ultrasonic units were demonstrated at the meeting with Northwest Airlines NDE Staff in Minneapolis, MN in August, 2000. The modules have also been demonstrated to Panametrics and KB engineers.

January-March, 2001: Development of the conformable scanning system was completed. The scanner was tested on the aircraft parts, the results have been sent to AANC, Boeing, and Cessna. The portable scanning modules have been demonstrated to QMI and GFM staff.

April-September, 2001: A conformable scanning system for application on the aircraft structures with curved surfaces was tested on the wing structures of the SA 227 aircraft during field tests at the Berry Aviation, San Marcos, TX, Perimeter Aviation, Winnipeg, MB, and Superior Aviation, Iron Mountain, MI. The scanning system was also successfully demonstrated at the Metro Operators Conference 2001 in Las Vegas.

October, 2001-March, 2002: A conformable scanning system was demonstrated to Northwest Airlines NDE staff at NWA Maintenance Facility in Minneapolis, MN. The scanner was tested on the cut-off from the DC-10 horizontal stabilizer. Several dry coupling transducer modules with adjustable incident angles have been designed, manufactured, and tested on the calibration specimens for DC-10 horizontal stabilizer and Cessna wing structure.

Publications:

"Ultrasonic Imaging Of Fatigue Cracks Around Fasteners In Multilayered Airplane Structures", Proceedings of the 1998 Advances in Aviation Safety Conference & Exhibition, SAE, 1998.

"Ultrasonic Imaging Of Cracks In Aging Aircraft Structures", Paper Summaries of the 1998 ASNT Conference, ASNT, 1998.

"Miniature Scanners For Ultrasonic Imaging Of Fatigue Cracks In Airplane Structures", Paper Summaries of the 1999 ASNT Conference, ASNT, 1999.

"Portable Scanning And Positioning Modules For Integration Of NDE Sensors**",** Presented at QNDE 2000, published in Review of Progress in QNDE, Volume 20.

"Modular Imaging Systems For Ultrasonic Evaluation Of Aircraft Structures", Proceedings of the International Symposium on Nondestructive Testing Contribution to Infrastructure Safety Systems in the 21st Century, Torres, Brazil, 1999.

"Modular Systems For Ultrasonic Imaging In Manufacturing", Proceeding of National Manufacturing Week Conference 2000, NAM/ASME, 2000.

"Modular Imaging Systems For Ultrasonic Evaluation Of Aircraft Structures", NDT.NET, March 2000.

"Characterization Of Fatigue Cracks In Multi-Layer Aircraft Structures Using Portable Ultrasonic Modules", Presented at ASIP 2000, published in Proceeding of ASIP 2000.

"Accuracy Of Fatigue Crack Characterization Using Ultrasonic Scanning", presented at QNDE 2001.

"Application Of Portable Modules For Fatigue Crack Characterization" in Advanced Nondestructive Evaluation for Structural and Biological Health Monitoring, Proceedings of SPIE, Vol. 4335, 2001.

"Portable Ultrasonic Systems For Quantitative Characterization Of Fatigue Cracks In Aging Aircraft"**,** Proceeding of The Fourth Joint NASA/FAA/DoD Conference on Aging Aircraft, NASA, 2001**.**

"Multi-Element Adjustable Transducer Arrays For Ultrasonic Scanning Of Aging Aircraft", in Proceedings of SPIE, 2002.

Task Title: Contact Transducer Optimization for Engine and Airframe Inspection

Investigation Team: T. Gray, Iowa State University; K. Smith, J. Umbach; Pratt & Whitney; J. Kollgaard, S. LaRiviere, Boeing.

Program initiation date: Program initiated as IA014 June 23, 1998 with scheduled ending date of October 31, 2002.

Objective:

- To provide a tool for the development, evaluation, or optimization of contact UT inspection of critical aviation components such that in-service inspections can be implemented in a rapid fashion when durability issues arise.
- To develop a UT contact transducer models for flaw and noise predictions for use in probe design and technique development/evaluation, including tolerance variation assessment.
- To work with the industry partners to validate the model results and develop software tools that are useable in typical engineering environments.

Research Activities:

- Define typical applications. Contact UT inspection sees widespread use in both engine and airframe applications. Determination of the adequacy of a contact inspection protocol typically involves consideration of component geometry, surface roughness, and material effects. Inspection optimization tools that allow consideration of probe design, technique evaluation, and tolerance variation are needed.
- Develop tool that considers component geometry, (non-parallel surfaces, surface curvature, defect orientation, defect location, flaw morphology), surface roughness, and material effects (noise, attenuation).
- Develop tool for probe design, technique evaluation, and tolerance variation that addresses wedge coupling, beam shape, multiple sound paths, multiple UT modes (i.e. corner trap, longitudinal reflection, shear, tip diffraction, and surface wave)

Anticipated Results:

- Computational tool for use in inspection design and optimization

Accomplishments:

November 2000: Software breakthrough, viz. Display and manipulation of 3-D object and ray tracing results in Windows/PC environment.

October 2001: Successful compile of full software, including CAD, 3D display, ray tracing, UT beam and flaw modeling.

February 2002: Two new OEM example problems initiated (propeller shaft, fan blade) with PW.

Publications:

Mike Garton and Tim Gray, “A Software Package for Simulating Ultrasonic Inspections in 3D CAD Geometry,” presented at Review of Progress in QNDE, Brunswick, Maine, July 29 – August 3, 2001.

Task Title: Scanning Pulsed Eddy Current for Aviation Applications

Investigation Team: Principal Investigators: J. R. Bowler, M. Johnson, Iowa State University; D. Moore, AANC, D. Wilson, B. Jappe, Boeing-Long Beach; S. LaRiviere, J. Thompson, Boeing - Seattle. Commercial Airlines: Morris Johnson, NWA

Students: Shaun Linsay and Fahad Azeem, Iowa State University

Program initiation date: Program initiated as IA026 September 25, 1998 with scheduled ending date of October 31, 2002.

Objective:

- To transition the pulsed eddy current (PEC) technology from the developer to the user community and to facilitate its rapid introduction and acceptance in commercial aviation.
- To develop and demonstrate new PEC-based detection and characterization methods for small fatigue cracks in multilayered aircraft structures.
- To transition the PEC methodologies for corrosion and crack detection in cooperation with the industrial partners.

Research Activities:

- Provide 1st generation PEC hardware/software for industry evaluation for corrosion and crack detection applications
- Adaptation existing system to commercial scanner
- Initiate crack detection studies to assess sensitivity and optimize probe designs for industry applications
- Develop 2nd generation system with industry feedback
- Demonstrate 2nd generation system on industry defined applications

Anticipated Results:

- Improved pulsed eddy current system for use in aviation applications including familiarization of the technique with the commercial aviation community

Accomplishments:

April, 1998: Initial planning meeting with FAA and representatives from Boeing Seattle and Boeing Long Beach.

June, 1998: Demonstration of the PEC scanner at NWA-Minneapolis.

December, 1998: New generation of the PEC software completed. Two PEC boards have been fabricated. Detailed communication with the OEM partners has determined the integration strategy. System transferred to Boeing-Seattle for field testing.

February, 1999: Visit to Boeing, St. Louis. Information exchange on ISU PEC and Boeing MAUS systems.

June, 1999: Visit to Boeing, Seattle to discuss first generation PEC performance evaluation.

August, 1999: Visit to AANC for field evaluation trials of the first generation PEC system.

November,1999: Visit to Cessna for discussion on arrangements for making measurements on test specimens.

May, 2000: Laboratory prototype of the second generation PEC system completed.

October, 2000: Completed pulsed eddy current simulation software for the analysis of flaw signals.

August, 2001: Participation in the AANC structured corrosion experiment.

August, 2001: Visit to Cessna for an evaluation of the 2nd generation PEC system.

April, 2002: Participated in SAIC round-robin corrosion experiment for the evaluation of different pulsed eddy current technologies.

Publications:

"Corrosion Evaluation Using a Pulsed Eddy-Current Instrument", Review of Progress in Quantitative Nondestructive Evaluation, Ames, Iowa, July 2000.

"Improved Pulsed Eddy-Current Measurements On Subsurface Defects Using Differential-Reflection And Hall-Device Probes", Electromagnetic Nondestructive Evaluation, Des Moines, Iowa, August 1999.

"Improved Pulsed Eddy-Current Measurements On Subsurface Defects Using Differential-Reflection And Hall-Device Probes", Review of Progress in Quantitative Nondestructive Evaluation, Montreal, July 1999.

Task Title: Infrared Detection of Ultrasonically Excited Cracks

Investigation Team: Bob Thomas, L.D. Favro, Xiaoyan Han – Wayne State University

Program initiation date: June 14, 2000

Objective:

- To develop the new technology of Sonic Infrared Imaging for use in aircraft inspection.
- To explore potential applications of Sonic IR for NDI of aircraft structures.
- To design a prototype Sonic IR Inspection System that is specifically adapted for NDI of aircraft structures.
- To initiate technology transfer.

Research Activities:

- Study the limits of detectability of cracks in different structures and optimize sonic transduction including different methodologies for coupling the sound to various aircraft structures
- Evaluate signal processing methodologies for weak signals and/or small cracks including algorithms for thresholding and automation of defect recognition
- Perform laboratory testing on representative specimens and parts removed from aircraft and complete field evaluation at AANC

Anticipated Results:

- Design of a prototype system and plan for technology transfer

Accomplishments:

November 2000: Imaged a 20±2 μm long fatigue crack in samples provided by USAF and cracks in a DC-10 nose wheel. Also found evidence that thermosonics imaging can detect "kissing" disbonds that are missed by pulsed (flashlamp excitation) thermography (and therefore, also likely to be missed by ultrasonic inspection).

March 2001: Assembled a working version of a hand-held thermosonic system for on-aircraft work. Successfully obtained agreement between first modeling results and laboratory specimens. Completed a field trip to AANC and tested both the table-top and hand-held systems on targets of opportunity. Hand-held system was successfully tested on both internal framing members and fuselage skin, with cracks found in both.

June 2001: Conducted analytical and computational modeling of crack images. Bought a second 20kHz ultrasonic source from Branson Ultrasonics using WSU funds. Began use of the new Indigo Systems high resolution IR camera. Began work on a noise reduction algorithm for thermosonic images.

November 2001: Initiated laser vibrometer measurements on cracked metallic samples with a borrowed vibrometer. Ordered a vibrometer using WSU funds.

January 2002: Tested 40kXz system. Built a pneumatic system for holding ultrasonic gun.

Publications:

"Sonic Infrared NDT for Crack Detection", Xiaoyan Han, Lawrence D. Favro, and Robert L. Thomas, ASNT, Portland, OR, March 19, 2002.

"Thermosonic NDE for Aircraft Structures", Xiaoyan Han, L.D Favro, and R.L. Thomas, UDRI, Dayton, OH, Dec. 3, 2001.

"Investigation of Thermosonics for Crack Detection in Turbine Engines", Xiaoyan Han, L.D Favro, and R.L. Thomas, DARPA Workshop, Arlington, VA, Dec. 12, 2001.

"Thermosonics: Detecting Cracks and Adhesion Defects Using Ultrasonic Excitation and Infrared Imaging", Xiaoyan Han, L.D. Favro, Zhong Ouyang, and R.L. Thomas, The Journal of Adhesion, 76, 151-162, (2001).

"Sonic Infrared Imaging of Fatigue Cracks," L.D. Favro, R.L.Thomas, Xiaoyan Han, Zhong Ouyang, Golam Newaz, and Dominico Gentile, The International Journal of Fatigue, 23, pp. 471-476, (2001).

“Sonic IR Imaging of Cracks and Delaminations,” ,” L.D. Favro, Xiaoyan Han, Zhong Ouyang, Gang Sun, and R.L. Thomas, Analytical Sciences, 17, 451-453 (2001).

Task Title: Aging Characterization and Lifetime Assessment of Polymeric Insulation in Aircraft Wiring

Investigation Team: L. C. Brinson, S. Carr, T. Mason, K. Shull – Northwestern University

Students: Tao Bai and Nelson Nunalee; postdoc T. Ramanathan

Program initiation date: May 23, 2000

Objective:

- To identify the critical aging mechanisms for aircraft wiring.
- To develop a reliable test method based on IS for assessing the aged state of aircraft wire.
- To develop predictive models to describe the degradation of wire insulation.

Research Activities:

Examination of the problem of aging of electric wire insulation is under way to determine the best methods to routinely characterize insulation integrity in existing aircraft as well as to provide insight as to how health monitoring could be installed as an integral component of new aircraft. The work consists primarily of the development of an impedance spectroscopy technique that could be used as an *in situ* test method for intact wiring. This work is being supplemented by standard characterization methods, such as Fourier transform infrared spectroscopy (FTIR), optical microscopy and scanning electron microscopy. Both naturally aged and laboratory aged wires are being evaluated. Identification of the primary aging mechanisms as well as suitable nondestructive testing techniques are under way. Results of the research effort will help define the impact of aging factors on wire insulation and provide tools to predict and detect critical degradation levels.

Anticipated Results:

- Provide the best methods to routinely characterize insulation integrity in existing aircraft as well as to provide insight as to how health monitoring could be installed as an integral component of new aircraft
- Provide sound scientific basis for new regulations/codes regarding standard testing procedures and intervals for wiring in aircraft
- Methods for characterization of wiring for use in prediction and detection of critical degradation levels.

Accomplishments:

January 2002: Ongoing exchange and contact with Martin W. Kendig, Rockwell Scientific. Focus on correlation between IS results and broadband impedance results.

March 2002: Ongoing exchange and contact with Dave Puterbaugh, Analog Interfaces. Focus on mechanical degradation of PVC as measure of aging and wire insulation quality. Correlation with IS results.

Publications:

The Boeing Company, AACE Symposium, 14 November 2000, "Impedance spectroscopy to Investigate Aircraft Wire Insulation Aging", T. Bai (presenter), L. C. Brinson, T. O. Mason, K. Shull.

K. R. Shull, L. C. Brinson, F. N. Nunalee, T. Bai, T. O. Mason, S. H. Carr, *Aging Characterization of Polymeric Insulation in Aircraft Wiring Via Impedance Spectroscopy*, Proceedings of the 5th Joint Conference on Aging Aircraft, Orlando, Florida, 10-13 September (2001).

Task Title: Modeling Optimization Tools of MOI Technology

Investigation Team: L. Udpa, Iowa State University; B. Shih, Physical Research Inc.

Students: Liang Xuan and Zhewei Zeng

Program initiation date: Program initiated as IA040 September 25, 2001 with scheduled ending date of September 25, 2002.

Objective:

- To develop a finite element code for simulating the eddy current MOI inspection geometry.
- To work with the industrial partner in the validation and application of the MOI inspection model for aviation applications.

Research Activities:

- Provide understanding of effect of layer thickness and air gaps between layers of MOI response
- Use model as experimental testbed for parametric studies varying bias fields, frequency, excitation level, industrial foil thickness as function of defect type/size
- Use prediction of magnetic fields to optimize imaging process
- Validate the model in cooperation with industry partners

Anticipated Results:

MOI is applicable to detection of corrosion and second layer cracking with large coverage area and easy-to-interpret images. Most research efforts have focused on improved hardware and electronics. Improvements are needed in MOI film sensors to lead to POD improvements. A numerical model for simulating physical processes helps make more informed design decisions.

Accomplishments:

May 2000: Completed initial model validation for simple crack and corrosion geometries.

September 2000: Attended ATA NDT Forum in SFO for discussion of the work with industry partners.

June 2001: Completed parametric studies for 1st layer corrosion (corrosion depth, diameter, frequency, effect of 2nd layer) and 2nd layer corrosion domes (corrosion on top and bottom of 2nd layer).

March 2002: Completed parametric studies of circumferential cracks in dimpled countersinks underneath rivet heads.

Publications:

R. Albanese, G. Rubinacci, A. Tamburrino, A. Ventre, F. Villone, L. Xuan, B. Shanker, and L. Udpa, “A Comparative Study of Finite Element Models for Magneto Optic Imaging Applications”, ENDE 2001, University of Cassino, Italy, June 2001.

L. Udpa, W. C. L. Shih, and G. F. Fitzpatrick, “Improved Magneto-Optic Sensors for Detection of Subsurface Cracks and Corrosion in Aging Aircraft”, Aging Aircraft 2001, The 5th Joint NASA/FAA/DoD Conference on Aging Aircraft, September 10-13, 2001, Hyatt-Orlando, Florida.

L. Xuan, Z. Zeng, B. Shanker, and L. Udpa, “Development of a Meshless Finite Element Model for NDE Applications”, ACES Conference, Monterey, California, March, 2002.

Task Title: NDI Guidance Material for FAA Aircraft Certification Engineers

Investigation Team: Lisa Brasche and David Eisenmann in response to requests from members of the Aircraft NDI Technical Community Research Group (TCRG).

Students: C. Cyrzan

Program initiation date: Awarded as IA042, September 17, 2001

Objective:

- To relate the role of NDE to the overall lifecycle of aviation components including implications for damage tolerance and safe life design strategies.
- To provide NDE resources, both written and electronic, to support the decision process for FAA certification engineers regarding the effective utilization of NDE technology.
- To determine the effectiveness of delivery of instructional content in various media including the use of written documents, CD based tools including simulations and videos.

Research Activities:

- Establish training design panel in cooperation with TCRG
- Update existing materials for NDI course for FAA Aviation Safety Inspectors
- Utilize training design panel for review of modules
- Transition materials (written, electronic media) to FAA field offices and industry
- Survey effectiveness of delivery mechanism for use in future training development efforts

Anticipated Results:

- Revised materials for existing FAA ASI course
- NDI web-based resources for ASIs and certification engineers
- Guidance materials for NDI tailored for aviation use

Accomplishments:

January 2002: Initial discussions with FAA-AFS personnel to define updates to the existing NDI training course offered by the FAA Training Academy

April 2002: Review meeting with FAA-AFS personnel to review materials for first two training modules

June 2002: First draft of two training modules delivered to FAA-AFS personnel for distribution by review team. Initiation of updates to remaining six modules.

Task Title: Enhanced Flaw Detection Using Hall Probes For Aircraft Inspection

Investigation Team: John Bowler, Marcus Johnson, Garry Tuttle, Iowa State University

Students: Haiyan Sun and Micah Decker

Program initiation date: Awarded as IA043, September 17, 2001

Objective:

- To develop a new Hall probe technology with improved detection capability and to accelerate inspections by using multi-sensor field measurements.
- To demonstrate a linear array for wide area rapid aircraft inspection.

Research Activities:

- Determine optimal material for use in Hall sensor using microelectronic fabrication facilities at ISU
- Fabricate and test Hall sensor to arrive at optimal design
- Build array of Hall sensors for use in inspection around fasteners and determine sensitivity
- Complete POD study using final probe design
- Provide comparison to conventional probe technology and document for FAA certification use

Anticipated Results:

- High sensitivity eddy current probes that exceed today's capability will be developed. These new sensors will address the need for smaller crack detection as defined by the FAA and OEMs.

Accomplishments:

September 2002**:** Program initiation. The laboratory work for this is project began in January 2002 at the Microelectronics Research Center, Iowa State University. The initial objective of the work is to fabricate Hall devices, measure their basic physical characteristics and assess the performance of these devices for magnetic field measurements in eddy current nondestructive evaluation.

Task Title: NDE Technology Assessment and Infrastructure Support

Investigation Team: Brian Larson, Rick Lopez, Iowa State University

Program initiation date: Awarded as IA044, September 17, 2001

Objective:

- To provide technical support at the request of the FAA on short term projects, sample preparation and technology base issues in cooperation with CASR and AANC staff.
- To produce an improved understanding and documentation of the science and techniques involved in inspection technologies identified with FAA and industry partners.

Research Activities:

- Short term projects identified by FAA that require inspection or materials characterization expertise. Program plan developed to address need in cooperation with requestor. After concurrence with FAA tech monitor, equipment resources and NDE staff from ISU are utilized to develop solution and document results as reports, guidance documents, or procedures
- Ongoing efforts include literature surveys of interest to aviation, and provision of samples to CASR and AANC

Anticipated Results:

- Literature reviews and summary reports of published data will also be prepared to provide an understanding of previous research results, with focus on aviation related data. This information is very useful when trying to understand current industry practices and when developing collaborative research efforts.

Accomplishments:

September 2001 – August 2002: Development of a sample set for use in evaluation of inspection techniques for crack detection typical of lap splice geometries. Supports information requested by the Airworthiness Assurance Working Group

September 2001: Evaluation of the effects of shot-peening on eddy current signal response in cooperation with Northwest Airlines.

November 2001 – March 2002: Support of FAA and NTSB in evaluation of the AA 587 incident.

Publications:

FAA Report “Study of the Factors Affecting the Sensitivity of Liquid Penetrant Inspections: Review of Literature Published from 1970 to 1998”, Brian Larson.

Task Title: Data Analysis Tools for Aircraft Inspections

Investigation Team: Lalita Udpa, Michigan State University with support from NWA, Delta, Honeywell

Students: Hemabh Shekar and Nathan Markey

Program initiation date: Awarded as IA045, September 17, 2001

Objective:

- To develop and transfer a signal processing software tool box for use by the OEMs in the inspection of aviation applications.
- To extend wheel inspection software tools to low frequency EC and incorporate into betasite tests at airlines and with the commercial vendor.

Research Activities:

- EC applications identified in cooperation with industry partners
    - Low frequency wheel inspection for subsurface/interior defect detection
    - Complicated feature inspection including edge effects (holes, slots, curvics, etc.)
- Taylor signal classification techniques to particular applications and incorporate into PC-based software
- Transition software to industry partners for betasite test
- Incorporate final product into existing EC inspection systems

Anticipated Results:

- Availability of the software can help in providing easy-to-interpret signal displays and powerful signal enhancement and classification algorithms. Work performed to date has demonstrated the application of the software to classification of eddy current signals obtained from aircraft wheel inspection and signals from dovetail slot inspection. Detection sensitivity can be improved with these tools leading to detection of smaller cracks and improved POD.

Accomplishments:

April 2001: Transition of software tool to ANDEC for incorporation into commercial wheel inspection system. Betasite test initiated with Delta Airlines.

June 2001: Transition of software tool to Honeywell for evaluation of engine disk slot eddy current inspection.

July 2002: Initiated discussion with commercial vendor to incorporate software into Honeywell inspection systems

Publications and Presentations:

L. Udpa, I. Elshafiey, and H. Shekar, “WINSAS: A New Tool for Enhancing the Performance of Eddy Current Inspection of Aging Aircraft Wheels”, Aging Aircraft 2001, The 5th Joint NASA/FAA/DoD Conference on Aging Aircraft, September 10-13, 2001, Hyatt-Orlando, Florida.

Task Title: Detection of Disbonds and Assessment of Structural Integrity of Composite Repairs for Aircraft Components

Investigation Team: Sameer A. Hamoush, Derome Dunn, Kunigal Shivakumar, Mathew Sharpe, North Carolina A&T University

Students: Anil Bhargava

Program initiation date: Awarded as IA046, September 17, 2001

Objective:

- To develop nondestructive testing to detect disbonds in composite repairs.
- To develop analytical models to assess degradation of strength and life of repaired parts.
- To test and verify the results.

Research Activities:

- Identify types and procedures of composite repairs. Generate/acquire samples with and without disbonds that are representative of the industry. Perform composite repair with and without disbonds on composite material parts. The repairs are to be performed according to aircraft manufacturers (such as Boeing) specifications, guidelines and/or standards.
- Perform NDE in cooperation with ISU-CASR. Perform destructive measurement of damage to map damage size, mechanical properties, fatigue life and residual strength and correlate to NDE for pristine components.
- Develop FEM for stress and fracture mechanics analysis to assess the severity of the disbond and correlate to measured strength and life of repairs
- Perform nondestructive testing of the repaired parts at CASR (Iowa State University) by use of C-SCAN and Computer Aided Tap Test (CATT) systems. Perform destructive measurement of damage in repaired parts to map the damage size, mechanical properties, fatigue life and residual strength.
- Correlate the measured damage to the NDT measurements and assess the detectability of NDT techniques. Develop finite element models and perform stress analysis along with fracture mechanics analysis to assess the severity of the disbond. Correlate the severity of Project Management.

Anticipated Results:

- Prototype system and demonstration data for range of crack detection applications defined by industry partners

Accomplishments:

December 2001: Kickoff meeting at ISU that included representatives from ISU, NCAT and FAA. Immediately proceeded by visit to NORDAM, a third party repair vendor in Oklahoma City.

April 2002: Team meeting at NCAT for coordination of inspection and composite repair aspects of the program. Included visit to Timco, a third party maintenance facility in Greensboro, NC. Computer aided tap test device delivered to NCAT for use in their work.

Task Title: Development of Nondestructive Inspection Methods for Repairs of Composite Aircraft Structures

Investigation Team: David K. Hsu (PI), Daniel J. Barnard, John J. Peters, Vinay Dayal, Iowa State University. Industrial partners will include Boeing, Northwest Airlines, American Airlines, AANC, CACRC, and British RAF

Students: Brian Danowsky and Zachary Nielsen

Program initiation date: Awarded as IA047, September 18, 2001

Objective:

- To develop nondestructive inspection and evaluation methods that can provide quantitative information and images to aid the accept/reject decision making for repaired parts. Such techniques, with an ability to map out the morphology and mechanical condition of a repair, will provide the inspector with technical records of the repaired component while it remains in-service.

Research Activities:

- Survey existing repair methods and flaw types of concern. Acquire representative samples from industry partners for NDI development and destructive characterization
- Compare performance of CATT to mechanical impedance analysis and bond testing including use of AANC round-robin data/samples
- Develop protocol for use of CATT including correlation between images and repair morphology
- Transition results to industry partners including on-going evaluation with Iowa Army National Guard

Anticipated Results:

With increasing use of composites on control surfaces and primary load-bearing structure of the aircraft, quality assurance of repairs made on such components is essential to continued airworthiness. Field practice relies largely on hearing-based manual tap tests. Recent development of CATT (computer aided tap test) and availability of air coupled UT offers opportunities to understand the morphology and condition of a repair, to establish a correlation between imaged features and the actual internal state of the repair, leading to accept/reject criteria for repaired components that promote safe operation.

Accomplishments:

September 2001: Project initiated based on input from industry partners provided during the field tests of the computer aided tap tester (CATT). The CATT was commercialized in 2001 and will also be utilized as an assessment tool in this new project.

December 2001 and May 2002: Team meetings with NCAT composites team for coordination of project activities.

November 2001 – March 2002: Support of FAA and NTSB evaluation of the AA587 crash.

Publications and Presentations:

"NDE of Repairs on Aircraft Composite Structures," David K. Hsu, Daniel J. Barnard and John J. Peters, Proc. of SPIE, Vol. 4336, *Nondestructive Evaluation of Materials and Composites V,* edited by G. Y. Baaklini, E. S. Boltz, S. M. Shepard and P. J. Shull, 100-107, 2001.

"Development of Nondestructive Methods for Composite Repair Inspection", David K. Hsu, D. J. Barnard, J. J. Peters and V. Dayal, Review of Progress in Quantitative NDE, Bellingham, WA, July 14-19, 2002.

"Nondestructive inspection of composite and their repairs," D. K. Hsu, D. J. Barnard, J. J. Peters, V. Dayal and V. Kommareddy, 6th FAA/DoD/NASA Aging Aircraft Conference, San Francisco, CA, September, 2002

"Imaging Composite Honeycomb Structures using Computer Aided Tap Test and Air Coupled Ultrasound," ASNT Fall Conf. Nov. 4-8, 2002.

"Nondestructive Inspection of Repairs on Composite Aircraft Structures," David K. Hsu and Daniel J. Barnard, Review of Progress in Quantitative NDE, Brunswick, ME, July 29 - August 3, 2001.

"NDE of Composites: Quantitative evaluation of damage," David K. Hsu, FAA/NASA Workshop on Composites, Hampton, VA, June 2001.

Task Title: Nondestructive Evaluation of Premium Aerospace Castings

Investigation Team: J. Gray (PI), F. Inanc, T. Jensen, J. Xu, Iowa State University with support from Boeing, Howmet, Northrop Grumman, Hitchcock

Students: J. Zhang

Program initiation date: Awarded as IA048, September 18, 2001

Objective:

- To develop optimal NDE inspections for complex aerospace castings and evaluate elements of image formation that can affect image quality, such as scattering and unsharpness effects
- To develop POD models for x-ray images and a means of determining inspection coverage for complex parts
- To develop image processing methods to enhance detectability in the presence of diffraction mottling and for use with digital radiography detectors such that improvements are provided in the detectability over unprocessed images

Research Activities:

- Develop tools to ensure adequate coverage using multiple inspection orientations/zones as necessary
- Determine effects of scattering for new real-time detectors and incorporate into modeling tools
- Establish the limits of image processing tools for use in realtime inspection of cast components
- Develop stereography method for use in location and characterization of typical casting defects

Anticipated Results:

Castings are seeing wider application in critical aerospace components both in airframe and propulsion applications. To ensure their safe introduction into critical applications, radiographic inspection in combination with knowledge of the effects of flaw morphology/location on part life are often required. Changes are also occurring in x-ray inspection technology, all with implications for FAA's regulatory role. Understanding limitations of inspection technology and assessing the role of inspection in life management decisions is needed. Tools from this program will be available to assist FAA in engineering decisions regarding safe implementation of cast components.

Accomplishments:

September 2001: Program initiation that builds on prior tasks in this area. Effort at ISU has focused on inspection decisions regarding castings. A companion project at Northwestern University has explored the relationship between casting design through development of casting process modeling and crack growth mechanisms. The work enjoys the support of a wide industry segment including both the casting suppliers and the OEMs.

Publications and Presentations:

FAA Casting Workshop, November 6th, at Northwestern.

Task Title: Multi-Element Adjustable Transducer Arrays For Applications With Portable Ultrasonic Flaw Detectors

Investigation Team: Igor Komsky, Northwestern University with support from Boeing-Long Beach, Boeing-Seattle, Northwest Airlines, Cessna, AANC, Panametrics, Krautkramer-Branson, Sigma, and Technisonic.

Program initiation date: Awarded as IA049, September 20, 2001

Objective:

- To develop a set of the multi-element adjustable ultrasonic transducer arrays for use in a variety of ultrasonic inspection procedures.
- To transfer the technology for aircraft industry use.

Research Activities:

- Develop methodology to determine optimal number, types, and spatial orientations of transducer array elements based on spatial orientations/size of aircraft structural elements and defects
- Develop multi-element transducer-positioning head
- Integrate transducer positioning head and coupling unit with transducer module.
- Demonstrate unit at AANC and validate on specific application
- Transfer methodology for development and applications of the transducer arrays to industry

Anticipated Results:

Prototype system and demonstration data

Accomplishments:

September 2002: Program initiation.

Publications:

"Multi-Element Adjustable Transducer Arrays for Ultrasonic Scanning of Aging Aircraft", in Proceedings of SPIE, 2002.

Task Title: Magnetic Particle Inspection Improvements for Aerospace Applications

Investigation Team: David Jiles, Mike Garton, Rick Lopez, and Lisa Brasche, Iowa State University with support from United Airlines, Pratt & Whitney and Boeing

Students: J. Y. Lee and S. J. Lee

Program initiation date: Awarded as IA050, September 25, 2001

Objective:

- To provide fundamental support to the aviation community in the area of magnetic particle inspection including publication of the literature survey that summarizes factors affecting the inspection sensitivity.
- To develop a user friendly, PC based simulation model for magnetic particle inspection for use by the OEMs in the inspection of aviation applications.

Research Activities:

- Characterize equipment variability and understand effect on sensitivity with theoretical support as needed
- Develop PC-based simulation tool for design of MPI including complex parts
- Betasite testing and validation of tool in partnership with industry partners
- Transfer of final tool to industry partners
- Publication of literature survey that summarizes factors affecting inspection sensitivity
- Reference material available for FAA certification use

Anticipated Results:

Simulation tool for use in optimizing mag particle inspection

Engineering data for validation

Accomplishments:

September 2002: Program initiation. Initial effort concentrated on gathering industry input regarding expectations for the final simulation tool.

Task Title: MOI Sensor Improvements

Investigation Team: Bill Shih, Jerry Fitzpatrick, PRI; Lalita Upda, MSU. The work will be undertaken in a cooperative industry/university/government arrangement with the technical team led by PRI Research and Development Corporation (PRI)-- inventors and developers of MOI technology—with contributions by Northrop-Grumman Synoptics (Synoptics) (producer of the MO sensors), Michigan State University (ISU), and Ohio State University (OSU). MSU will perform electromagnetic (finite-element) calculations designed to guide sensor improvements, and OSU will provide expertise in the solid-state physics of garnet films.

Students: Jason Slade (MSU)

Program initiation date: Awarded as IA051, September 25, 2001

Objective:

- To significantly enhance the crack detection sensitivity of MOI-based systems through improvements to sensor design and performance leading to expanded use of MOI in the nondestructive inspection of aging aircraft systems.
- To improve the performance of MOI for subsurface crack and corrosion detection in applications of interest to FAA and the industry.

Research Activities:

- Evaluate different chemical compositions for the out-of-plane sensors and methods of film growth
- Perform electromagnetic (finite-element) calculations, designed to guide the sensor development and improvement process
- Fabricate prototype sensors based on empirical studies and calculations
- Evaluate improvements from new sensors and demonstrate

Anticipated Results:

Increase in air travel and a growing population of aging aircraft leads to growing inspection requirements to ensure continued aircraft airworthiness and a need for cost-effective NDI techniques that are accurate, reliable, and easy to use. Magneto-Optic Imaging (MOI) has gained wide acceptance for detection of both surface and subsurface defects in commercial aircraft. However detection of smaller defects such as corrosion and fatigue cracks in multi-layer aircraft structures could be improved with development of new sensor materials used in the device.

Accomplishments:

September 2002: Program initiation.

Publications:

Paper submitted to 6th Joint FAA/DoD/NASA Aging Aircraft Conference: “Improved Magneto-Optic Sensors for Detection of Subsurface Cracks and Corrosion in Aging Aircraft”.

Task Title: Engineering Assessment of Fluorescent Penetrant Inspection

Investigation Team: Lisa Brasche, Rick Lopez, Dave Eisenmann, Bill Meeker, ISU; Clint Surber, Steve Younker, Boeing – Seattle; Dwight Wilson, Boeing – Long Beach; Lee Clements, Delta Airlines; Tom Dreher, United Airlines; Kevin Smith, John Lively, Pratt & Whitney; Bill Griffiths, Keith Griffiths, Pramod Khanderwal, Rolls Royce; Sam Robinson, Sherwin; and Ward Rummel, D&W Enterprises

Students: S. Gorman

Program initiation date: Awarded as IA052, September 28, 2001

Objective:

- To identify factors for where engineering data is insufficient, assess parameter ranges that provide acceptable performance for typical aircraft and engine components, and document results for use in revision of industry specifications
- To develop a self–assessment tool and protocol for use by airline and overhaul shops for performance verification compared against industry–accepted performance
- To complete assessment of process control and monitoring tools and provide needed improvements
- To develop/validate FPI guidance materials

Research Activities:

- Define factors for which engineering data is deficient
- Design engineering study that provides quantitative assessment of performance and complete study using either lab or shop facilities as appropriate
- Transition process to airlines for internal, self-assessment
- Distribute results through use of web and support changes to industry specifications as warranted
- Utilize results to update/create guidance materials

Anticipated Results:

- Engineering data and FPI resource website for publication of data
- Guidance materials for use by industry and FAA
- Development of a self assessment tool and protocol

Accomplishments:

September 2001: Program initiation. Monthly conference calls have been used to maintain communication between the eight participating organizations.

January 2002: Program kickoff meeting which helped to identify industry research needs for additional engineering data. Based on input at the January meeting, over fifty items were identified and later prioritized.

March 2002: Engineering Studies Plan completed. Twelve separate studies are planned.

May 2002: Drying Study completed at Delta Airlines facility in Atlanta. Data analysis is underway.

Publications:

"Engineering Assessment of Fluorescent Penetrant Inspection: New Research Efforts",Lisa Brasche, Iowa State University, and Alfred L. Broz, FAA Chief Scientist and Technical Advisor for NDE, to be published in 6th FAA/NASA/DOD Aging Aircraft Conference